EXHIBIT B

LINCOLN MEMORIAL UNIVERSITY
LAW REVIEW

VOLUME 7 FALL 2020 ISSUE 2

ARC MAPPING METHODOLOGIES & THE PURSUIT OF MAGICAL GLOBULES, NOTCHES, & BEADS:

A BRIDGE TOO FAR TO ESTABLISH FIRE ORIGIN?

By *Thomas R. May, Esq.* and *David J. Icove, Ph.D., P.E.*

"The witness stand is not a circus—there is no 'Come One, Come All' sign inviting anyone who wishes to speak to step right up. Instead, witnesses and their proposed testimony must meet certain requirements."[1]

I. INTRODUCTION

Expert fire investigators know the limits of arc mapping as an indicator of fire origin. Concerns about arc mapping are on the rise.

There are doubts associated with arc-related artifacts, distinguishing "cause" from "victim" beads, visual vs. microscopic examinations, and even practitioner qualifications. Specific noteworthy complaints include: (1) overpromises on the technique's precision, (2) exaggerated inferences from the

[1] Burgett v. Troy-Bilt LLC, No. 12-25-ART, 2013 WL 3566355, at *1 (E.D. Ky. July 11, 2013).

available data, (3) failure to adequately account for potential methodological flaws, (4) deficient scientific rigor in establishing evidentiary fire origin-related reliability, (5) errors due to deficient practitioner training and experience, and (6) indeterminate findings based upon subjective visual analysis. An emerging industry of pseudoscientific expert witnesses compounds these problems. Untrustworthy and invalid fire-related arc mapping clothed as forensic science continues to invade the courtroom.[2]

II. AREA OF ORIGIN

NFPA 921 cites that the foundation of most forensic fire investigations is an accurate identification of a fire's origin area, which is defined as a "general geographic location within a fire scene, in which the 'point of origin' of a fire or explosion is reasonably believed to be located."[3] NFPA 921 identifies four principal methods for establishing fire origin: (1) witness information and/or electronic data, (2) fire patterns, (3) arc mapping, and/or (4) fire dynamics.[4] "An incorrect determination of a fire's origin generally leads to an incorrect determination of its cause."[5]

The methodology to determine a fire's area of origin is presently in flux. "The literature review of fire pattern usage in the fire investigation profession illustrates several gaps with the overall process of using damage to determine an area of

---

[2] Vytenis Babrauskas, *Arc Mapping: New Science, or New Myth?*, FIRE AND MATERIALS, 2017 15th International Conferences, 2017, at 890-904 ("Careful consideration of engineering principles and large-scale experimental studies on the subject indicates that the relevance and prominence of arc mapping as a leading indicator of fire origin is greatly overstated. The technique is valid and applicable only in some very limited scenarios.").

[3] *See* NFPA 921, *Guide for Fire and Explosion Investigation*s, National Fire Protection Association, Quincy, MA, 2017, (*hereinafter* NFPA 921), at 3.3.12.

[4] *See* NFPA 921, at 18.1.2.

[5] *See* HANGER, CHARLIE, *FORENSIC SCIENCE ASSESSMENTS: A QUALITY AND GAP ANALYSIS – FIRE INVESTIGATION* 6 (2017).

origin."[6] "Complex fire conditions can create fire patterns and burn damage that can be easily interpreted by the fire investigator as 'multiple areas of origin.'"[7] "Not understanding the role of ventilation in a fire's development is a leading factor in mistaking the origin."[8] "Fire damage created by ventilation can be, and often is, deeper, lower and more pronounced than fire damage in the fire's area of origin, leading even experienced fire investigators to easily misidentify the fire's area of origin."[9]

III. FIRE COMPARTMENT DYNAMICS

Fire dynamics, a complex subject area, "is the study of how fires start, spread and develop."[10] "To characterize fire behavior meaningfully, fire dynamics must incorporate the interaction of chemistry and material science and the engineering disciplines of fluid mechanics and heat transfer."[11] "Fire and flame plumes, layer depths and temperatures, rates of heat release, ventilation, and radiant fluxes, all grow, peak, and decay throughout the life of a fire event."[12] As a result, fuel

---

[6] Gregory E. Gorbett et al., *Use of Damage in Fire Investigation: A Review of Rire Patterns Analysis, Research and Future Direction*, 4 FIRE SCI. REV. 4, 31 (2015), https://firesciencereviews.springeropen.com/articles/10.1186/s40038-015-0008-4 (last visited July 20, 2020).

[7] *See generally id.*

[8] Steven W. Carman, *The Impact of Ventilation in Fire Investigation*, DRI – The Voice of the Defense Bar, DRI FIRE SCI. AND LITIG. SEMINAR, 2013. https://www.dri.org/ (last visited July 20, 2020).

[9] Parisa Dehghani-Tafti & Paul Bieber, *Folklore and Forensics: The Challenges of Arson Investigation and Innocence Claims*, 119 W. VA. L. REV. 549 (2016).

[10] *See* FIRE DYNAMICS, https://www.nist.gov/el/fire-research-division-73300/firegov-fire-service/fire-dynamics (last visited June 28, 2020).

[11] Daniel Madrzykowski, *Fire Dynamics: The Science of Fire Fighting*, 10 INT'L FIRE SERV. JOURNAL OF LEADERSHIP & MGMT, 27 (2016).

[12] Gregory E. Gorbett, Ronald L. Hopkins, Kathryn C. Kennedy, & Patrick M. Kennedy, *Fire Pattern Persistence Through Post-Flashover*

load and ventilation are major influencing factors in an enclosure fire event.[13]

IV. FIRE PATTERN ANALYSIS

Fire patterns are defined as "[t]he visible or measurable physical changes, or identifiable shapes, formed by a fire effect or group of fire effects."[14] Fire effects are described as "the observable or measurable changes in or on a material as the result of a fire."[15] Fire pattern analysis entails "the process of interpreting fire patterns to determine how the patterns were created."[16] "Currently, no systematic method exists for fire investigators to identify a fire pattern."[17]
"Due to the large number of variables and unknowns which have not yet been conclusively established by scientific research, 'burn pattern analysis' cannot be considered as rising

---

Compartment Fires, Sarasota: John A. Kennedy & Associates, at 10, https://www.researchgate.net/profile/Gregory_Gorbett/publication/238671199_FIRE_PATTERN_PERSISTENCE_THROUGH_POST-FLASHOVER_COMPARTMENT_FIRES/links/57b7682e08ae6f173764ee3b.pdf (last visited July 20, 2020).

[13] *See* SABER, H.H. ET AL., NAT'L RES. COUNCIL OF CAN. A NUMERICAL STUDY ON THE EFFECT OF VENTILATION ON FIRE DEVELOPMENT IN A MEDIUM-SIZED RESIDENTIAL ROOM, P. 1 (2008) ("[f]ire load characteristics, room geometry and ventilation conditions will impact the course of the fire"); BJORN KARLSSON & JAMES G. QUINTIERE, ENCLOSURE FIRE DYNAMICS, 2.2.2 (1999) ("[a] fire in an enclosure can develop in a multitude of different ways, mostly depending on the enclosure geometry and ventilation and the fuel type, amount, and surface area").

[14] *See* NFPA 921, at 3.3.74.

[15] *See* NFPA 921, at 6.2.1.

[16] *See* NFPA 921, at 6.1.1.

[17] *See Gorbett, supra* note 6 at p. 2 ("[p]resently, much of this interpretation is implicit and subject to investigator bias, with assignment of interpretation to patterns being largely dependent on the investigator's knowledge, experience, education, training and skill, without the benefit of a structured framework to help guide the investigator through the process").

to the level where it is a recognized forensic discipline."[18] Nevertheless, fire investigators use fire patterns "to trace the course of the fire and, by reversing that process, establish the area of origin of the fire."[19] "The fire patterns, both movement patterns and intensity patterns, change continuously during the life of [a] fire,"[20] and are also greatly influenced by ventilation and available fuel.[21]

V. ARC MAPPING METHODOLOGY

An 'arc' is "an electrical discharge occurring between two electrodes"[22] that produces extremely high temperatures. Conductors commonly found in electrical installations are usually made of metal, namely copper or aluminum. "Arcing can only happen when a cable is energized. Once a circuit protector trips, arcing ceases. As the fire spreads, it consumes more wiring insulation, but there won't be any other evidence of arcing left anywhere else on those wires."[23]

---

[18] NAT'L. INST. OF STANDARDS AND TECH., ANN. BIBLIOGRAPHY ON "BURN PATTERN" QUESTIONS 1 (2015) *available at* https://www.nist.gov/system/files/documents/forensics/Annotated-Bibliography-Burn-Pattern.pdf.

[19] DAVID J. ICOVE & GERALD A. HAYNES, KIRK'S FIRE INVESTIGATION 249-50 (2018).

[20] Gorbett et al., *Fire Pattern Persistence Through Post-Flashover Compartment Fires,* at 10.

[21] *See* David J. Icove & John D. DeHaan, *"Hourglass" Burn Patterns: A Scientific Explanation for their Formation*, INT'L SYMP. ON FIRE INVESTIGATION PROC., NAT'L ASS'N OF FIRE INVESTIGATORS, Sarasota, Fla. (2006) ("[t]hese burn patterns are influenced by a number of variables including the available fuel load, ventilation, and the physical configurations of the room").

[22] *See* Ravel F. Ammerman & P.K. Sen, *Modeling High-Current Electrical Arcs: A Volt-Ampere Characteristic Perspective for AC and DC Systems*, 39TH NORTH AMERICAN POWER SYMPOSIUM (IEEE), 58-62 (2007).

[23] Vladimir Chlistovsky, *Arc Mapping - Finding The Forensic Needle in a Haystack*, ORIGIN AND CAUSE (Jan. 11, 2017) https://origin-and-cause.com/articles/arc-mapping-finding-the-forensic-needle-in-a-haystack/.

Melting caused by electrical arcing is described as follows:

> Electrical arcing produces very high temperatures and localized heating in the path of the arc, which typically melts electrical conductors at the locations where the arc makes contact with them. Because the arc itself is normally small in area and short in duration, the arc damage is localized, with a sharp line of demarcation between the melted and unmelted portions of the conductor. Due to the high temperature and rapid cooling of electrical arcing on conductors, polished cross sections of arc beads on stranded and solid conductors may show high internal porosity.[24]

Arc mapping entails "[t]he systematic evaluation of the electrical circuit configuration, [the] spatial relationship of the circuit components, and identification of electrical arc sites to assist in the identification of the area of origin and analysis of the fire's spread."[25] "Procedurally, arc mapping is simple. A floor plan has to be made that, if not of the whole structure, encompasses at least all areas potentially likely to be the area of origin. All circuits running through the area need to be traced. The wiring then is inspected for the presence of arcs, and those are recorded on the floor plan (map)."[26]

An arc mapping professional must have "the ability to accurately identify and locate arc sites on circuits."[27] "An adequate examination requires visual and tactile access to the entire circumference of the conduit or conductor . . . The most

---

[24] *See* NFPA 921, at 9.11.1.1.

[25] *See* NFPA 921, at 3.3.9.

[26] Babrauskas, *Arc Mapping: New Science, or New Myth?*, at 892.

[27] *See* D. Churchward & R. Cox, *The Benefits of Arcing*, INT'L SYMP. ON FIRE INVESTIGATION SCI. & TECH., NAT'L ASS'N OF FIRE INVESTIGATORS, Sarasota, Fla. (2010).

frequently used method of examination involves running lightly gloved hands along the length of the examination subject while using bright, oblique lighting to visually observe shadows cast by the light source. This sensory input provides two inputs to assist in locating anomalies."[28] NFPA 921 instructs practitioners to "[d]etermine if the surface anomaly occurred from arcing, environmental heat, or eutectic melting (alloying of metals)."[29]

Arc mapping "is a tedious process since it requires a detailed examination of all the conductors in the relevant building area, which is likely to be a painstaking process. In addition, it requires that the circuits be traced and identified, which can be difficult to do. This requirement may also make arc mapping impossible, since there are many fires where, due to the type of damages sustained, circuits cannot be successfully traced. In case of serious fires, structural collapses may produce a jumble of wires with no means of reassembling them into their original locations."[30]

VI. ARC MAPPING & FIRE ORIGIN

At present, there is an ongoing dispute in the fire investigation as to the value of arc mapping to establish fire origin, as opposed to arc sites being regarded merely as "fire patterns."

Delplace and Vos have stated that "[a] short circuit will normally take place wherever the fire first damages the cable. This gives us the point along the entire length of the circuit earliest affected by the fire."[31] Carey opined that there "is a high probability that arcing damage observed on electrical

---

[28] *See* NFPA 921, at 9.11.7.3.2.

[29] *See* NFPA 921, at 18.4.5.1.

[30] Babrauskas, *Arc Mapping: New Science, or New Myth?*, at 902.

[31] Delplace, M., & Vos, E., *Electric Short Circuits Help the Investigator Determine Where the Fire Started*, FIRE TECH. 19, 185-191 (1983); *see also* David J. Icove & Gerald A. Haynes, *Kirk's Fire Investigation* 249-50 (2018) ("[a]s a general principle, the arcing found farthest from the electrical source can help identify the area of origin").

conductors occurred in close proximity to the fire's area of origin."[32]

Conversely, Churchward, Cox, and Reiter declare:

> [t]he difficulty in this technique lies with those fires that have progressed beyond flashover. Under such conditions, the extent of destruction, the variability of materials' response to attack by fire, suppression activities and a host of other circumstances can make the determination of origin by fire pattern analysis unverifiable. Further confounding the problem is the lack of scientific verification that specific fire patterns can be created exclusively by specific fire effects[33]

And Babrauskas insists that "[a]rcing is more likely to be found at a place of concentrated fuel load, and at a location of local ventilation availability, than at the fire origin."[34]

---

[32] Carey, N.J., Developing a Reliable Systematic Analysis for Arc Fault Mapping, (2009) (unpublished PhD dissertation, Centre for Forensic Science - Pure & Applied Chemistry, University of Strathclyde, Glasgow) (available at https://strathprints.strath.ac.uk/27868/1/Arc_Mapping_research.pdf).

[33] Daniel L. Churchward, Ryan M. Cox & David Reiter, *Arc Surveys As A Means To Determine Fire Origin In Residential Structures,* INT'L SYMP. ON FIRE INVESTIGATION SCI. & TECH., NAT'L ASS'N OF FIRE INVESTIGATORS, Fire Service College, UK (2004) ("They should also be aware of limitations, such as incorrectly identifying arc melting artifacts, and the destruction of wiring due to structural collapse and post-flashover fire exposure"); NFPA 921 at 6.3.1.2.2 ("[d]etermining which pattern was produced at the point of origin by the first material ignited usually becomes more difficult as the size and duration of the fire increases").

[34] Vytenis Babrauskas, *Response, Letter to the Editor Re: Misinterpretations within the paper Arc Mapping: A Critical Review*,

NFPA 921 cautions:

> Full-scale, single-compartment testing has indicated that arcs may be more prevalent in the area of origin. However, there does not seem to be a direct correlation between the origin and arcing on conductors at the closest geometric point. Research continues on this issue.[35]

VII. ARC MAPPING & VISUAL EXAMINATION METHODOLOGY

"Seeing is a learned ability which an individual may improve *up to the limitations of the eye* and the nervous system . . . . Seeing is further affected by and incorporates other sensations and emotions, as well as past experience and *education*."[36] Sight can be hampered during fire investigations because "fire scenes are nearly always cold and badly burned, and the investigator must reconstruct the sequence of the fire backward from what is visible afterward to its point of origin."[37]

Some advocates of arc mapping believe that tactile and visual identification of arc sites by non-scientists is a reliable forensic methodology.[38] Other scientists have opined that this

---

personal communication on file with authors (June 13, 2018); *see also* Vytenis Babrauskas, *Arc Mapping: A Critical Review*, 54 FIRE TECH., 749-780 (Feb. 26, 2018). ("Only in rare cases where it might be demonstrated that fuel concentration or ventilation effects were not governing, would it be possible to use arc mapping results as pointers to the area of fire origin").

[35] *See* NFPA 921, at 9.11.7.5.1.

[36] JAMES H. RICHARDSON, OPTICAL MICROSCOPY FOR THE MATERIALS SCIENCES 98-99 (1971).

[37] DAVID J. ICOVE & GERALD A. HAYNES, KIRK'S FIRE INVESTIGATION, at 250 (2018).

[38] ATF Fire Research Lab., Visual Characteristics of Fire Melting on Copper Conductors, in TECH. BULLETIN 001 (Sept. 28, 2012) ("practice and training are the best ways to become proficient in identifying the difference between fire and arc melting").

cannot be so, that "the key physical *internal* indicators of an arc site" are dispositive.[39]

Both NFPA 921 and the Alcohol, Tobacco and Firearms (ATF) employ visual, and when necessary, microscopic examination of exterior characteristics of electrical conductors to identify arc sites or and/or beads.[40] ATF reports that the following traits are commonly revealed for *arc damaged* conductors (as opposed to conductors that were *melted* by fire:

> (1) Sharp demarcation between damaged and undamaged area (2) Round, smooth shape of artifact (3) Localized point of contact (4) Identifiable corresponding area of damage on the opposing conductor (5) Locally enlarged grain size (6) Resolidification waves (7) Copper drawing lines visible outside the damaged area (8) Localized, round depressions (9) Small beads and divots over a limited area, [and] (10) High internal porosity when viewed in a cross-section.[41]

---

[39] *See* Elizabeth C. Buc et al., *Method to Characterize Damage to Conductors* FIRE SCENES (2013) https://docplayer.net/36333412-Fire-and-materials-2013.html (last visited July 20, 2020; ("[d]efinitive *internal* arcing artifacts "are porosity throughout the bead or notch, irregular or lack of microstructure in the bead or notch and an area or line of demarcation between an arc site and the adjacent conductor," an examination that clearly entails microscopy"); *see also* RICHARD J. ROBY & JAMIE MCALLISTER, DEP'T OF JUSTICE, FORENSIC INVESTIGATION TECHNIQUES FOR INSPECTING ELECTRICAL CONDUCTORS INVOLVED IN FIRE, at 4. (2012) ("[t]he research findings clearly show that the sole use of visual characteristics to establish the energized state of a wire can lead to erroneous conclusions").

[40] *See* NFPA 921, at 9.11 ("Melted electrical conductors can be examined to determine if the damage is evidence of electrical arcing, melting by fire, or eutectic melting. Visual examination can provide reliable identification of damage from electrical arcing and melting by fire for most conductors."); *See also id*. at note 38.

[41] *See* NFPA 921, at 9.11.1.1.

The ATF states that, the physical descriptions of arc melting that can be readily identified by an investigator in the field, and do not require special instrumentation such as a scanning electron microscope, include:"[42] sharp line of demarcation, round smooth shape, localized point of contact, identifiable corresponding area of damage on opposing conductors, copper drawing lines visible outside the damaged area, localized round depressions, small beads and divots over a small area.[43]

Alternatively, it is opined that when melting is caused by fire (as opposed to electrical arcing), "the damage is spread over a larger area without a distinct line of demarcation between the melted and unmelted regions."[44] NFPA 921 offers further guidance:

> [c]onductors melted by fire may exhibit irregular or rounded globules, or smooth or rough tapered ends. The following traits are commonly exhibited for fire-melted conductors: (1) Visible effects of gravity on the artifact (2) Extended area of damage without a sharp demarcation from undamaged material (3) Gradual necking of the conductor — assuming this is not due to a mechanical break (4) Low internal porosity when viewed in a cross-section.[45]

NFPA 921 cautions that when interpreting damage to electrical systems, "[t]hese guidelines are not absolute, and that many times the physical evidence will be ambiguous and will

---

[42] ATF Fire Research Lab., *Visual Characteristics of Fire Melting on Copper Conductors*, in TECH. BULLETIN 001 (Sept. 28, 2012).

[43] *Id.*

[44] *See* NFPA 921, at 9.11.2.

[45] *Id.*

not allow a definite conclusion,"[46] and that "[i]n some cases, affirmative determination whether a particular conductor anomaly is an arc mark cannot be made in the field. In such cases, the mark should be identified, located, and treated as if it were an arc until a further determination can be made."[47]

Nevertheless, "[a]t a recent conference on Fire Investigation Science and Technology, fire investigators rejected a premise that arc melting could not be reliably distinguished from fire melting based on visual assessment only."[48] Others argued that "[t]he research findings clearly show that the sole use of visual characteristics to establish the energized state of a wire can lead to erroneous conclusions."[49]

Also, in a recent presentation at the Winter 2019 Meeting of The National Academy of Forensic Engineers (NAFE), Orlando, Florida, four experts in forensic fire investigation presented a protocol of practice for the examining damaged conductors the by accepted laboratory methods.[50] In the modern forensic laboratory, there are five techniques used to further study localized damage to conductors, other electronic devices, and appliance subcomponents. These analytical techniques include: 1) cleaning by ultrasonic and/or plasma etching; 2) visual examination; 3) imaging by stereomicroscopy and/or radiography; 4) chemical analysis by Energy Dispersive X-ray Spectroscopy; and 5) examination of microstructure by metallography. The various techniques and their ability to

---

[46] *See* NFPA 921, at 9.10.1; *see also* NFPA 921 at 9.11 ("more advanced examination techniques including SEM/EDS, X-ray, CT scanning (i.e., X-ray computed tomography), cross-sectioning and polishing, or other metallurgical methods could assist in discerning between damage by electrical arcing and melting by fire respectively").

[47] *See* NFPA 921, at 9.11.7.3.3.

[48] Elizabeth C. Buc et al., *Method to Characterize Damage to Conductors from Fire Scenes* 657-666; *see also* TECHNICAL BULLETIN 001 at 1 ("We take issue with . . . the incorrect conclusion that fire investigators cannot visually differentiate between fire and arc melting when examining conductors.").

[49] Roby, *Forensic Investigation Techniques* (2012).

[50] Elizabeth C. Buc et al. *The Status of Arc Mapping*, WINTER 2019 MEETING OF THE NAT'L ACAD. OF FORENSIC ENG'RS (NAFE), Orlando, Fla. (January 5-6, 2019).

distinguish between the various causes of damage to conductors is illustrated in Figure 1.

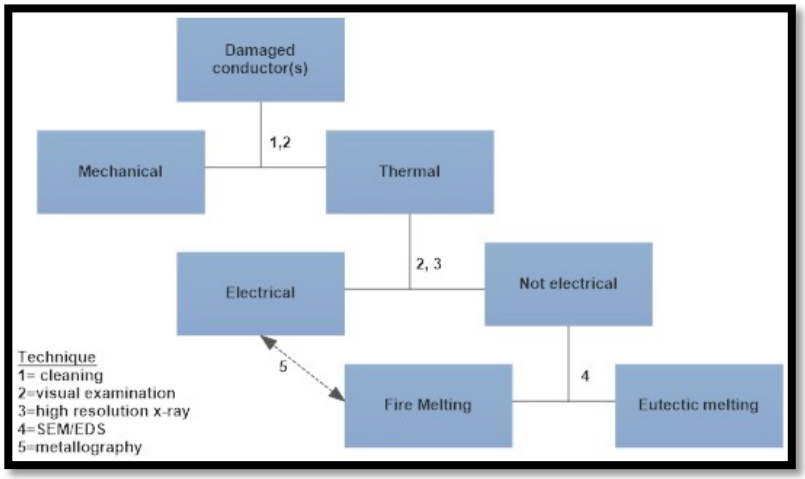

Figure 1. Protocol for the examination of damage to copper conductors from fire scenes.[51]

In *Zens v. Slatkin & Co.*, a battle of arc mapping experts ensued.[52] One expert contended that the opposing expert's "opinions are unreliable because he does not accept that a sharp line of demarcation is proof of an electrical arcing event which . . . renders his scientific methodology unreliable because it has no basis in scientific fact."[53] In response, it was pointed out that the opinion of the challenging professional "is unreliable because it is based upon an NFPA guideline which will soon be revised."[54]

VIII. CAUSE VS. VICTIM BEADS

---

[51] Buc et al., *The Status of Arc Mapping* (2019).

[52] Zens v. Slatkin & Co., CIV No. 11-1023, 2014 WL 1165874 at *2 (D.S.D. Mar. 18, 2014).

[53] *Id.*

[54] *Id.*

The "current state-of-the-art in the field . . . states that beads can only be formed on energized wires."[55] However, some opine that electrical conductor-related artifacts formerly identified as arc faults can be formed as the result of fire damage.[56] In fact, Hussain asserted that "the research results showed that the energized state of the wire had no consistent effect on the visual or macroscopic characteristics formed during heating. Round copper globules with clear lines of demarcation, traditionally defined as 'beads', were produced on both energized and non-energized wires."[57] Buc further stated that "[i]t is now widely accepted that 'cause' arcs cannot be distinguished from 'victim' arcs based on laboratory examination only."[58]

IX. MICROSCOPIC ARC EXAMINATIONS

Materials science is "the scientific study of the properties and applications of materials of construction or manufacture (such as ceramics, metals, polymers, and

---

[55] ROBY & MCALLISTER, FORENSIC INVESTIGATION TECHNIQUES FOR INSPECTING ELECTRICAL CONDUCTORS INVOLVED IN FIRE, at page 3.

[56] ROBY & MCALLISTER, FORENSIC INVESTIGATION TECHNIQUES FOR INSPECTING ELECTRICAL CONDUCTORS INVOLVED IN FIRE, at page 3 ("No trends or distinguishing visual or microscopic characteristics between energized and non-energized wires have been found in the samples reviewed to-date. Whether a wire was energized with load, energized without load, or non-energized had no significant effect on the visual or microscopic characteristics of the wire."). https://www.ncjrs.gov/pdffiles1/nij/grants/239052.pdf (last visited July 20, 2020).

[57] Nasir Hussain, Jamie L. McAllister & Richard J. Roby, *Analysis of Beads Formed on Energized and Non-Energized Electrical Copper Conductors Exposed to Various Thermal Insults*, Int'l Symp. on Fire Investigation Sci. and Tech. (ISFI), 305-316 (2012).

[58] Buc et al., *Method to Characterize Damage to Conductors from Fire Scenes at* 657-66; *but see* Buc et al., *Method to Characterize Damage to Conductors from Fire Scenes* at 657-66 ("Internal porosity was found to be the key indicator to distinguish between arc melting and fire melting").

composites)."[59] Metallurgy is defined as "[t]he branch of engineering concerned with the production of metals and alloys, their adaptation to use, and their performance in service; and the study of chemical reactions involved in the processes by which metals are produced, and the laws governing the physical, chemical, and mechanical behavior of metallic materials."[60]

"Materials taken from a fire scene can be analyzed visually on both a macroscopic and microscopic level. X-ray diffraction and scanning microscopy can be used for structural examination, and gas chromatography and mass spectrometry for chemical analysis."[61] In metallurgy, the principal purpose of microscopic examination is to show details of metal structures which are too small to be seen with the unaided eye. Microscopic metallurgical examinations "can be used to determine grain size, inclusions, previous heat treatments, possible causes for failures, deformation, and intergranular corrosion."[62]

The measurement of temperature is of highest importance in metallurgy.[63] High-temperature metallurgical

---

[59] *Materials Science*, MERRIAM-WEBSTER.COM, https://www.merriam-webster.com/dictionary/materials%20science (last visited June 29, 2020).

[60] *Metallurgy*, DICTIONARY OF MATERIALS SCIENCE (1st Edition, 2003).

[61] Robert A. Schroeder & Robert B. Williamson, *Application of Materials Science to Fire Investigation* (1999) (dissertation, University of California, Berkeley), https://www.schroederfire.com/ras_diss/start-here.html (last visited July 20, 2020).

[62] DELL K. ALLEN, METALLURGY THEORY AND PRACTICE 109 (1969).

[63] *Id.* at 129; *see generally* Daudi R. Waryoba & Peter N. Kalu, *Textural and Microstructural Inhomogeneities in Drawn and Annealed OFHC Copper Wire*, 495-97 MATERIALS SCIENCE FORUM 213 (Sept. 15, 2005) ("This work presents the results of a study on textural and microstructural inhomogeneities that develop during annealing of heavily drawn Oxygen free high conducting (OFHC) copper wire"); W. Yan, J. Chen, & X-H. Fan, *Effects of Grain Boundaries on Electrical Property of Copper Wires*, 13 (5) TRANSACTIONS OF THE NONFERROUS METALS SOCIETY OF CHINA 1075-79 (Oct. 2003) ("By means of

reactions . . . [can cause] structural changes, such as fusion, sintering, and excessive reduction of internal porosity and surface area."[64]

> Such technical identification measures as macrostructure testing, metallographic analysis, microanalysis of appearance, analysis of composition and the like have been used in [the] analysis and identification of material evidence as marks remanded on electrical fire scene, and a series of technical methods of identifying material evidence as electrical fire marks have been set up which have been applied in material evidence as marks identification of practical fire cases and have provided scientifically and reliably technical bases.[65]

---

annealing at different temperatures, the copper wires with various numbers of grain boundaries were achieved"); M. Tajfara, E. Ganjehb, & M.H. Mirbagheria, *Evaluation of copper brazed joint failure by thermal-fatigue test applicable in heat exchangers*, 656 JOURNAL OF ALLOYS AND COMPOUNDS 347-56 (2016) ("Fracture strength values at three different temperatures were determined at a constant number of 100 thermal cycles. Fractography analysis revealed that all cracks propagated along the center regions which adopted ductile morphology changing to brittle one by increasing the test temperature"); Kuan-Heng Liu et al., *Microstructural Study on Molten Marks of Fire-Causing Copper Wires* 8 (6) MATERIALS 3776-90 (2015) ("In this study, we scrutinized the microstructures of fire-causing copper wires and simulated the external environmental conditions required for the formation of fire-causing arc beads."); Ying Wu et al., *The Surface Analysis of Melted Arc Copper Beads* 561-65 MATERIALS SCIENCE FORUM 2455-58 (2007) ("Specific studies were carried out on the characteristic component from interior surfaces (IS) of cavities in metallic fire debris by Auger electron spectroscopy (AES), especially in order to distinguishing the primary and secondary electrical short circuit (ESC) arc beads.").

[64] SESHADRI SEETHARAMAN, FUNDAMENTALS OF METALLURGY 3 (Seshadri Seetharaman, Woodhead Publishing) (2005).

[65] Mana b. Di et al., *Study of Analyzing Characteristic of Composition on the Surface of Copper Conductor Melted Marks, The 5th Conf. on*

X. ARC MAPPING PRACTITIONERS

"An electrical engineer is not required to perform arc mapping. Arc mapping is fundamentally pattern recognition,[66] which fire investigators routinely perform in other areas of fire investigation. In some cases, however, an electrical engineer may be required for calculation of available short-circuit current or circuit-tracing activities, but these are not necessarily required for arc mapping performed for origin determination. Similarly, a metallurgist may assist in determining whether a particular conductor anomaly is the result of an arc."[67]

"Little is known about the consistency and accuracy of conclusions among experienced investigators when presented with the same data."[68] "The other difficulty for forensic scientists investigating fires is that the observations of damage after the fire may often times be independent of the path taken by the fire making it difficult to identify where the fire started."[69]

XI. ARC MAPPING & LEGAL CONSIDERATIONS

Performance-Based Fire and Fire Engineering, 11 PROCEDIA ENGINEERING 68-74 (2011); *see also* Mei-meia b.c. Wei et al., *The Experiment on Melted Mark Formed by Copper Wire in Electrical Fire and the Analytic Researcher on the Feature Parameters of Metallographic Structure*, *The 5th Conf. on Performance-Based Fire and Fire Engineering*, 11 PROCEDIA ENGINEERING 504-13 (2011) (discussing influences of heating conditions to the metallographic structure characteristics).

[66] *See* Almirall, *Forensic Science Assessments: A Quality and Gap Analysis*, at 19-20 ("[r]esearch conducted since 2005 reveals that in some cases, the ability of a fire investigator to determine the correct area of origin in a fully involved room by only interpreting fire patterns may be no better than random chance").

[67] *See* NFPA 921, at 9.11.7.2.

[68] *See* Almirall et al., *Forensic Science Assessments: A Quality and Gap Analysis,* at 25 (2017).

[69] Gregory E. Gorbett et al., *Use of Damage in Fire Investigation: A Review of Fire Patterns Analysis, Research and Future Direction*, 4 FIRE SCI. REV. 1 (2015), https://firesciencereviews.springeropen.com/articles/10.1186/s40038-015-0008-4 (last visited July 20, 2020).

A. AN OVERVIEW

Currently, the unreliability of the underlying techniques in the absence of laboratory confirmation requires too great of an analytical leap to support an expert opinion, and as a result, amounts to mere unsupported speculation.

Arc mapping evidence and testimony must pass muster under *Daubert* and the federal rule of evidence governing the admission of expert testimony. "While much is known about the behavior of fires in building enclosures, using that knowledge to determine where a particular fire started and what caused it can be very challenging and is based on subjective judgments and interpretations."[70]

"The subjective aspects of arc-fault interpretation and area of fire origin determinations ensure that the methodology will remain contested in the arena of legal controversy for some time to come."[71] At present, field-based arc mapping is besieged by: (1) limited non-peer-reviewed scientific literary support, (2) insubstantial research, and (3) idiosyncratic visual and tactile testing techniques. The addition of ill-equipped non-metallurgic practitioners into the mix assures a resulting consequence of stacked and tenuous inferences along with unsupported and unreliable speculation.

B. EVIDENTIARY RULE 702 & ARC MAPPING

---

[70] *See* Almirall et al., *Forensic Science Assessments: A Quality and Gap Analysis*, at 13.

[71] Buc et al., *Method to Characterize Damage to Conductors from Fire, at pp. 657-666*; *but see* Buc et al., *Method to Characterize Damage to Conductors from Fire Scenes,* at 657-66 ("Internal porosity was found to be the key indicator to distinguish between arc melting and fire melting").

"An expert must testify within the reasonable confines of his subject area."[72]

An arc mapping proponent must navigate complex legal rules as a prerequisite to offering expert testimony. A Rule 702 analysis is a gatekeeping tool designed to weed out unreliable scientific opinions and "has two steps: first, the Court determines whether the expert is qualified to render the proffered opinion, and second, the Court examines whether the opinion itself is reliable."[73]

Rule 702, Testimony by Expert Witnesses states:

> A witness who is qualified as an expert by knowledge, skill, experience, training, or education may testify in the form of an opinion or otherwise if:
> (a) the expert's scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue;
> (b) the testimony is based on sufficient facts or data;
> (c) the testimony is the product of reliable principles and methods; and
> (d) the expert has reliably applied the principles and methods to the facts of the case.[74]

"Whether a witness is qualified as an expert can only be determined by comparing the area in which the witness has superior knowledge, skill, experience, or education with the subject matter of the witness's testimony."[75] Rule 702 simply requires that: (1) the expert be qualified; (2) the testimony address a subject matter on which the factfinder can be assisted

---

[72] Scottsdale Ins. Co. v. Deere & Co., 115 F. Supp. 3d 1298, 1303 (D. Kan. 2015).

[73] United States v. Crabbe, 556 F. Supp. 2d 1217, 1221 (D. Colo. 2008).

[74] Fed. R. Evid. 702.

[75] Carroll v. Otis Elevator Co., 896 F.2d 210, 212 (7th Cir. 1990).

by an expert; (3) the testimony be reliable; and (4) the testimony "fit" the facts of the case.[76]

C. KNOWLEDGE AND QUALIFICATIONS

"Knowledge," within Rule 702, "means that if the scientific or other specialized knowledge will assist the trier of fact in understanding the evidence and determining facts in issue, then that expert may testify if the testimony is based upon more than subjective belief or unsupported speculation."[77] "'Specialized knowledge' is knowledge beyond common or ordinary knowledge and experience."[78] "Scientific knowledge" can be defined as "that which is grounded in the methods and procedures of science or "derived by the scientific method."[79] When scrutinizing the 'knowledge' prong of Rule 702, one factor that courts consider "is whether other experts exist who are more specifically qualified."[80]

A fire investigation is "[t]he process of determining the origin, cause, and development of a fire or explosion."[81] NFPA 1033: Standards for Professional Qualifications of a Fire Investigator, states, in pertinent part:

> [T]he investigator shall have and maintain at a minimum an up-to-date basic knowledge of the following topics beyond the high school level:
>
> (1) Fire science
> (2) Fire chemistry

---

[76] *Id.* (quoting Fed. R. Evid. 702 advisory committee's note).

[77] Wilson v. Petroleum Wholesale, Inc., 904 F. Supp. 1188, 1190 (D. Colo. 1995).

[78] Walters v. S & F Holdings LLC, No. 14–cv–02006–REB–MJW, 2015 WL 5081689, at *1 (D. Colo. Aug. 28, 2015).

[79] United States ex rel. M.L. Young Const. Corp. v. Austin Co., No. CIV-04-0078-T., 2005 WL 6000505, at 1 (W.D. Okla. Sept. 29, 2005).

[80] Stagl v. Delta Air Lines, Inc., 117 F.3d 76, at 81 (2d Cir. 1997).

[81] NFPA 921, at 3.3.73.

(3) Thermodynamics
(4) Thermometry
(5) Fire dynamics
(6) Explosion dynamics
(7) Computer fire modeling
(8) Fire investigation
(9) Fire analysis
(10) Fire investigation methodology
(11) Fire investigation technology
(12) Hazardous materials
(13) Failure analysis and analytical tools
(14) Fire protection systems
(15) Evidence documentation, collection, and preservation
(16) Electricity and electrical systems.[82]

Electrical engineering is "a type of engineering that deals with the uses of electricity."[83] An electrical engineer is a person who uses scientific knowledge to design, construct, and maintain electrical devices.[84]

Typical core courses taken by an electrical engineer include:

- Digital Logic
- Embedded Systems I: Introduction
- Electric Circuits
- Signals and Systems I
- Electronic Circuits and Systems
- Problem Solving Methods and Tools for Electrical Engineering
- Energy Systems and Power Electronics

---

[82] NFPA 1033, *Standard for Professional Qualifications for Fire Investigator*, National Fire Protection Association, Quincy, MA, 2017, (*hereinafter* NFPA 1033), at 1.3.7, p. 6.

[83] *Electricity,* MERRIAM-WEBSTER.COM, https://www.merriam-webster.com/dictionary/electrical%20engineering (last visited June 10, 2020).

[84] *Electrical engineer,* COLLINSDICTIONARY.COM, https://www.collinsdictionary.com/us/dictionary/english/electrical-engineer (last visited June 10, 2020).

- Electromagnetic Fields and Waves
- Probabilistic Methods for Electrical Engineers
- Communication Systems I or Signals and Systems II
- Integrated Electronics or Semiconductor Materials and Devices.[85]

Conversely, metallurgy involves understanding the composition and behavior of metals and routinely requires the application of microscopic methodologies. Conventional core courses taken by a metallurgical engineer include:

- Chemistry
- Corrosion Engineering
- Energy Resources
- Engineering Mechanics
- Experimental Techniques in Metallurgy
- High-Temperature Chemical Processing
- Hydrometallurgy
- Materials Science and Engineering
- Mineral Processing
- Physical Metallurgy
- Physics
- Statistics
- The Mineral Industries and the Environment.[86]

Conductors in electrical installations usually consist of copper or aluminum metals. Arc mapping involves obscure and scientific facts related to metal, namely, a distinct understanding of the electrical and thermal conditions, which can produce notches, beads, and other artifact damage on

---

[85] *Electrical Engineering Degree Requirements*, IOWA STATE UNIVERSITY, https://www.ece.iastate.edu/academics/bachelors-degree-requirements/#core (last visited June 10, 2020).

[86] *Metallurgical Engineering*, THE PRINCETON REVIEW 178 BB, https://www.princetonreview.com/college-majors/174/metallurgical-engineering (last visited June 10, 2020).

electrical wires.[87] Metallurgical failure analysis is the process by which a metallurgist determines the mechanism that has caused a metal component to fail.[88] Therefore, competent members of the metallurgical community must necessarily provide the essential scientific knowledge required to evaluate electrical conductor surface anomalies reliably.

Although fire investigator qualifications are often overlapping and interwoven with other scientific disciplines, apples are not oranges. It may be that some general scientific principles apply to both electrical engineering and metallurgy. Even so, most fire investigators and/or electrical engineers do not possess professionally based, specialized scientific knowledge about metallurgy and are therefore not qualified to give an opinion involving forensic metallurgy, phase transformations in metal and alloys, or to conduct a high magnification examination of electrical conductor artifacts.

In *Cole's Tool Works v. Am. Power Conversion Corp*., a forensic electrical engineer with decades of experience in investigating electrical aspects/causes of fire and other events confirmed the reliability of his opinions through published, peer-reviewed literature, testing, and *independent metallurgical analysis*.[89]

D. SKILL

Skill is defined as "knowledge of a work activity which requires the exercise of significant judgment."[90] Skill has also been expressed as "practical and familiar knowledge of the principles and processes of an art, science or trade, combined with the ability to apply them in practice in a proper and

---

[87] V. Barbrauskas, *Arc Mapping: A Critical Review*, 54 Fire Tech. 749-80 (2018), available at https://link.springer.com/article/10.1007/s10694-018-0711-5 (last visited Aug. 2, 2020).

[88] S.V. Hainsworth, *Critical Assessment 26: Forensic Metallurgy-The Difficulties*" 33 (14) MAT. SCI. AND TECH.1553-59 (2017).

[89] Cole's Tool Works v. Am. Power Conversion Corp., No. 2:06CV169-P-A, 2009 WL 901764 (N.D. Miss. Mar. 31, 2009) (*emphasis added*).

[90] *Skill,* BLACK'S LAW DICTIONARY (10th ed. 2014).

approved manner."[91] "'Special skill' is defined as 'a skill not possessed by members of the general public and usually requiring substantial education, training or licensing."[92] Skill entails more than mere competence; it involves special abilities and proficiencies cultivated through concentrated groundwork and practice.

Arc mapping involves the application of an amalgamation of visual, tactile, and microscopic methodologies to distinguish elemental characteristics and patterns of metals. Electron dispersive spectrometry, grain sizing, layer thickness assessment, and phase determinations are designated areas of skilled expertise usually not found in an electrical engineering or a fire investigative toolbox. Running a lightly gloved hand or a cotton ball along the length of an electrical conductor is not a "skill" as contemplated by Rule 702. Instead, this field-based methodology is merely the loose and untrustworthy application of purportedly objective scientific causation standards. As a result, exploration of the nexus between an arc mapping practitioner's skills and proposed testimony on many occasions will reveal a problematic and insurmountable analytical gap.[93]

E. EXPERIENCE

"Experience" is "practical knowledge, skill, or practice derived from direct observation of or participation in events or a particular activity."[94] "Specialized experience" consists of "experience that equipped the [individual] with the particular knowledge, skills, and abilities to perform successfully the duties of the position, and that is typically in or related to the

---

[91] Locklear v. Colvin, No. 5:14-CV-154-BO, 2014 WL 6606572, at *2 (E.D.N.C. November 19, 2014).

[92] United States v. Palo, No. 97-50167, 1999 WL 51507, at *1 (9th Cir., Jan. 22, 1999).

[93] *E.g.*, Hayes v. Carroll, 314 S.W.3d 494, 504 (Tex. Ct. App. 2010) (focus is on the "fit" between the subject matter at issue and the expert's familiarity of the subject matter).

[94] *Experience,* MERRIAM-WEBSTER.COM, https://www.merriam-webster.com/dictionary/experience (last visited June 10, 2020).

work of the position to be filled."[95] "Occupational experience" is "the kind which is obtained casually and incidentally, yet steadily and adequately, in the course of some occupation or livelihood."[96] The Advisory Committee Notes to Rule 702 states, in pertinent part:

> If the witness is relying solely or primarily on experience, then the witness must explain how that experience leads to the conclusion reached, why that experience is a sufficient basis for the opinion, and how that experience is reliably applied to the facts. The trial court's gatekeeping function requires more than simply "taking the expert's word for it."[97]

"Although extensive experience can make up for an absence in specialized training, if the witness does not possess superior knowledge, education, experience, or skill in the relevant area, the Court must exclude his or her testimony."[98]

Indispensable arc mapping experience focuses on determining if melting detected on electrical wiring is evidence of arc melting or thermal exposure.

The experience that consists of subjective value judgments concerning the presence or absence of particular

---

[95] Gladden v. Solis, No. 10-5475, 2011 WL 2274179, at *1 (E.D. Pa. June 9, 2011), aff'd, 490 F. App'x 411 (3d Cir. 2012).

[96] 2 JOHN H. WIGMORE, WIGMORE'S CODE OF EVIDENCE (3d ed. 1942).

[97] Advisory Committee Notes, Fed. R. Evid. 702.

[98] *In re* Mirena Ius Levonorgestrel-Related Prod. Liab. Litig. (No. II), 341 F. Supp. 3d 213 (S.D.N.Y. 2018); *see also* Whiting v. Boston Edison Co., 891 F. Supp. 12, 24 (D. Mass. 1995) ("[J]ust as a lawyer is not by general education and experience qualified to give an expert opinion on every subject of the law, so too a scientist or medical doctor is not presumed to have expert knowledge about every conceivable scientific principle or disease.").

electrical artifact characteristics is not a substitute for scientific laboratory examinations.

F. EDUCATION

Education is defined as "[t]he process of receiving or giving systematic instruction, especially at a school or university."[99] "'Higher education' is defined, generally, as education in advance of secondary education, including the work of colleges, universities, professional and technical schools."[100] Experiential education is defined as "integrat[ing] theory and practice by combining academic inquiry with experience."[101] Even considering an expansive definition, not all training or instruction can be defined as 'education.'

In *Derienzo v. Trek Bicycle Corp.*, an electrical engineer who was certified as a bicycling instructor was offered as an expert to opine upon the plaintiff's failure to warn and breach of warranty claims.[102] In this instance, the court stated:

> "[g]iven his lack of advanced scientific or technical training, however, I conclude that the [electrical engineer] is not qualified to testify about matters involving bicycle design or metallurgical engineering. ([the electrical engineer's] undergraduate degree was in electrical engineering; a bicycle is not an electrical device.)"[103]

---

[99] *Education*, OXFORDDICTIONARIES.COM, https://en.oxforddictionaries.com/definition/education (last visited June 11, 2020).

[100] 95 N.Y. JUR. 2D SCHOOLS, UNIVERSITIES, AND COLLEGES § 712 2020.

[101] Jan Wrenn & Bruce Wrenn, *Enhancing Learning by Integrating Theory and Practice,* INT'L J. OF TEACHING AND LEARNING IN HIGHER ED., 258-265 (2009).

[102] Derienzo v. Trek Bicycle Corp., 376 F. Supp. 2d 537, 563 (S.D.N.Y. 2005).

[103] *Id.* at 563.

Before arc mapping evidence is presented to a finder of fact, the expert report, curriculum vitae, and deposition testimony of the electrical engineer and/or fire investigator should be scrutinized for metallurgical-related educational qualifications and scientific expertise, including but not limited to: (a) specific coursework, (b) scientific research, (c) submission or publication of associated literature, (d) lecturing engagements, or (e) any other scholarly work in the areas of metallurgy or material science. Individuals proposing to testify about metallurgical issues must possess a demonstrated professional capability to assess the scientific significance of the underlying data and information to reliably opine their hypotheses with a trustworthy degree of certainty. Education that is minimally related and substantively insufficient will result in undependable conclusions. Briefly, the arc mapping proponent must demonstrate how her academic experiences establish the requisite expertise to testify about metal-related subject areas.

In general, there is a significant difference in the educational parameters of fire investigation practitioners and metallurgists. Specialized fire investigation training touches upon material science in a rudimentary fashion; most fire investigators scarcely have training classes in the relevant subjects, let alone achieve educational expertise. Adding fuel to the fire, "[t]here are insufficient educational and proficiency testing requirements for fire scene investigators."[104] Consequently, the proposed testimony is not within the reasonable confines of fire investigative sciences. Educational credentials that have little to do with material science may and should disqualify the fire investigator.

Also, merely having a degree and academic background in electrical engineering is insufficient to demonstrate specialized knowledge and experience that would enable an expert to provide meaningful opinion evidence relevant to the complex and multi-faceted issue of arc interpretations.

---

[104] *See* Almirall et al., *Forensic Science Assessments: A Quality and Gap Analysis*, at 9.

G. TRAINING

"Training is the process of learning the skills that you need for a particular job or activity."[105] "Training" is defined as "instruction or teaching designed to impart a specific skill, as opposed to general knowledge."[106]

Arc mapping encompasses conducting a metallurgical analysis to determine if an electrical event has transpired, or alternatively, observed fire artifacts that have merely been exposed to sufficient temperature to cause melting. Metallurgical-related training addresses the following: (a) understanding the science and engineering of materials, (b) microscopic structures of metals, (c) the relationship between the properties and composition of metal, (d) effects of temperature and time on metallurgical changes, and (e) metallurgical phases and microstructure changes.

Litigation-driven opinions and agendas based upon the subjective comparison of post-fire electrical artifacts to a lengthy list of visual characteristics that are supposedly indicative of arcing versus melting do gross disservice to courts and the delivery of justice. Visual and tactile approaches to arc interpretation are misapplications of the methodology and render the analysis unreliable and inadmissible.

H. THE EXPERT'S SCIENTIFIC, TECHNICAL, OR OTHER SPECIALIZED KNOWLEDGE WILL HELP THE TRIER OF FACT TO UNDERSTAND THE EVIDENCE OR TO DETERMINE A FACT IN ISSUE.

Rule 702's "helpfulness" standard requires a valid scientific connection to the pertinent inquiry as a precondition to admissibility.[107] An "expert's testimony is sufficiently grounded for purposes of litigation only if it will help trier of

---

[105] *Training,* COLLINSDICTIONARY.COM, (https://www.collinsdictionary.com/us/dictionary/english/training) (last visited June 11, 2020).

[106] 18 U.S.C. § 2339A(b)(2) (2020).

[107] Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, 591-92 (1993).

fact to reach *accurate* results."[108] A court will examine "the proffered connection between the scientific research or test result to be presented and particular disputed factual issues in the case."[109]

The melting of electrical conductors implicates numerous processes. Metallurgy, a traditionally known field of expertise requiring rigorous professional training, is the scientific domain that provides the connection between the melting of electrical conductors (e.g. arc melting vs. thermal melting vs. mechanical damage) and area of fire origin determinations.[110] Physical metallurgists determine metallurgical failure by scrutinizing the chemical, physical, and atomic properties and structures of metals.

On the other hand, electrical engineering is "a type of engineering that deals with the uses of electricity."[111] While courts have recognized expertise based on "professional experience" even where the proposed expert lacks the relevant credential, formal credentials are a requirement for qualification as an expert in many other scientific arenas. There are no indications that a general electrical engineering education includes any training in the area of metallurgy. Therefore, any allowed testimony would amount to a speculative inferential leap.

A cursory visual and tactile inspection of the post-fire physical characteristics of electrical conductors by pseudo-experts is not a scientific endeavor and does not rely upon any specialized knowledge and/or methodological expertise whatsoever. The need for accurate and trustworthy legal contribution transforms a common-sense issue into a scientific

---

[108] *In re* Paoli R.R. Yard PCB Litig., 35 F.3d 717, 744 n.12 (3d Cir. 1994).

[109] *Id.* at 743.

[110] *Metallurgy*, SCIENCE DAILY, https://www.sciencedaily.com/terms/metallurgy.htm (last visited June 12, 2020) (Metallurgy is the domain of "materials science and of materials engineering that studies the physical and chemical behavior of metallic elements and their mixtures.").

[111] *Engineering*, MERRIAM-WEBSTER.COM, https://www.merriam-webster.com/dictionary/electrical%20engineering (last visited June 11, 2020).

exercise involving the robust and exclusive scientific metallurgical approach.

Since non-metallurgists do not possess "scientific, technical, or other specialized knowledge" that would assist trier of fact as required by Rule 702, it is highly doubtful that expert testimony by pseudo-experts will be of any real assistance.

I. THE TESTIMONY IS BASED ON SUFFICIENT FACTS OR DATA.

Rule 702 also involves a quantitative analysis that utilizes necessarily complete data to ensure that conclusions reached are satisfactorily accurate and not merely the product of assumptions. "Sufficient data" necessitates the accurate representation of all relevant facts as well as not relying upon too much data that can be characterized as "assumptions." In addition, the term "data" is intended to encompass the reliable opinions of other experts. Briefly, the facts gathered must be complete, accurate, and reliable.

Peer-reviewed publications explaining arc mapping methodologies directs practitioners to conduct the investigation to disprove alternative hypotheses because "an expert's failure to explain or adequately disprove alternative theories of causation makes his or her theory speculative and conclusory."[112] Insufficient data renders an expert's testimony unreliable and invokes the parable of the five blind men who tried to identify the elephant.

For instance, NFPA 921 advises:

> [t]he investigator is cautioned to consider that conductors only pass through certain areas, and therefore, the amount of information available will be limited by the spatial distribution of the conductors available for arcing . . . [b]ranch circuits that are located behind some type of thermal barrier, such as gypsum board or plywood,

---

[112] Wal-Mart Stores, Inc. v. Merrell, 313 S.W.3d 837, 840 (Tex. 2010).

> may not provide useful arc mapping information. . .[113]

> Arc surveys can identify areas where the fire had damaged energized electrical conductors at some time in the fire's development. . . Fire damage to copper conductors can mimic arc damage, and visual inspection at the fire scene site may not be sufficient to correctly identify validate arc sites. If the analysis of the circuits incorrectly identifies damage on the conductors as arcing, hypotheses formed from the analyses will be based on flawed data and will be incorrect. The investigator may want to collect each perceived arc site for more detailed evaluation and verification.[114]

and

> Full-scale, single-compartment testing has indicated that arcs may be more prevalent in the area of origin. However, there does not seem to be a direct correlation between the origin and arcing on conductors at the closest geometric point. Research continues on this issue.[115]

The jury is still out where arc mapping methodologies are concerned.[116]

---

[113] NFPA 921, at 18.4.5.

[114] NFPA 921, at 18.4.5.6.

[115] NFPA 921, at 9.11.7.5.1.

[116] Cameron Novak, ATF Fire Research Lab., *Letter to the Editor in Response to 'Arc Mapping: A Critical Review,'* 54 FIRE TECH. 1 (2018). ("[A]rc mapping is a continuing topic of debate within the fire investigation community.") ATF Fire Research Lab., *Arc Mapping as a*

Intellectual rigor is preferred to scientific guesswork. Courts may and should refuse to admit expert opinion when there is simply too great an analytical gap between the data and the opinion proffered.[117] In many, if not all instances, characterization of conductor damage will require a protocol-driven laboratory examination to augment fire scene examinations.

J. THE TESTIMONY IS THE PRODUCT OF RELIABLE PRINCIPLES AND METHODS.

An expert opinion is reliable "if the knowledge underlying it has a reliable basis in the knowledge and experience of the relevant discipline."[118] "[A]ny step that renders the analysis unreliable . . . renders the expert's testimony inadmissible. This is true whether the step completely changes a reliable methodology or merely misapplies that methodology."[119] "More than blind trust is necessary . . . to reach the reliability level required of scientific expert testimony.[120]

There is no shortage of arc mapping skeptics. "The literature demonstrates that the reliability and validity of identifying arc sites is questionable. Also, the literature is divided on the question of reliability and validity relating to origin determination. Finally, the literature provides no

---

Tool for Fire Investigations, in Tech. Bulletin 001 (Mar. 17, 2017) ("The FRL also recommends further training and research on the principles and use of arc mapping in fire investigation.").

[117] General Electric Co. v. Joiner, 522 U.S. 136, 146 (1997) ("For example, there is no fit where a large analytical leap must be made between the facts and the opinion.").

[118] Pyramid Techs., Inc. v. Hartford Cas. Ins. Co., 752 F.3d 807, 813 (9th Cir. 2014).

[119] *Paoli,* 35 F.3d at 745.

[120] State v. Sharp, 395 N.J. Super. 175, 183 (2006).

discussion on proficiency testing."[121] "To date, no published research exists that measures the accuracy or error rate of any of these principles, much less a fire investigator's ability to bring these factors together to figure out where a fire started based on the arc mapping methodology."[122]

Many experts qualified in the field of metallurgy consider visual and tactile inspections standing alone to be an unreliable methodology and would require additional testing before reaching conclusions concerning electrical conductor damage. In *Meemic Ins. Co. v. Hewlett-Packard Co.*, the court found that an "[e]lectrical engineer's proposed testimony that cause of fire was unknown manufacturing defect in printer's power adapter would not assist jury, and thus was not admissible in action against printer manufacturer to recover for damages caused by fire, where engineer based his opinion on his visual observation that "damage [on power adapter was] much more severe than anything else," rather than on any scientific or technical expertise."[123]

At present, the significance of arc mapping imprecisions and limitations involving theory, techniques, and experimental verification demonstrate that it has limited capacity at best to establish an area of fire origin.

K. THE EXPERT HAS RELIABLY APPLIED THE PRINCIPLES AND METHODS TO THE FACTS OF THE CASE.

The relevant issue is whether a so-called-expert can reliably determine the cause of a post-fire metallic artifact through visual or tactile methods. As stated previously, arc mapping is subject to ongoing scientific debate because the techniques are supported by limited historical data and only a few case reports which contain significant inconsistencies and

---

[121] Gregory E. Gorbett & Wayne Chapdelaine, *Scientific Method – Use, Application, and Gap Analysis for Origin Determination,* INT'L SYMP. ON FIRE INVESTIGATION SCI.& TECH., at 10 (2014).

[122] Parisa Dehghani-Tafti & Paul Bieber, *Folklore and Forensics: The Challenges of Arson Investigation and Innocence Claims*, 119 W. VA. L. REV. 549, 560 (2016).

[123] Meemic Ins. Co. v. Hewlett-Packard Co., 717 F. Supp. 2d 752, 767 (E.D. Mich. 2010).

bias. Regardless, courts will consider "the reasonableness of using such an approach, along with [the expert's] particular method of analyzing the data thereby obtained, to draw a conclusion regarding the particular matter to which the expert testimony was directly relevant."[124]

Over the years, some investigators have erroneously accepted the presence of a conductor with balled or "beaded" ends as a prima facie indication of electrical arcing. Actual burning tests have demonstrated that balled ends can occur from flame exposure without the passage of electric current. In fact, "it was hypothesized that characteristic 'arc-beads' could be formed on non-energized wires as well as energized wires."[125] Furthermore, "[t]he key physical internal indicators of an arc site on both solid and stranded conductors are porosity throughout the bead or notch, irregular or lack of microstructure in the bead or notch and an area or line of demarcation between an arc site and the adjacent conductor."[126]

Undoubtedly, reliability in distinguishing "cause" arcs from "victim" arcs can best be confirmed through laboratory-based screening and confirmation. Cherry-picked facts and data that allow a "junk" science practitioner to unjustifiably extrapolate from accepted premises to unfounded and speculative conclusions are misleading and blatantly unreliable as a matter of law.

XII. ARC MAPPING & *DAUBERT* SCRUTINY

The gatekeeping application of *Daubert* admissibility analyses is an attempt, with varying degrees of success, to apply non-exclusive evaluative factors to weed out untrustworthy and/or suspect methodologies.[127] The overriding question is whether "the reasoning or methodology underlying the [proposed] testimony is scientifically valid and of whether that

---

[124] Kumho Tire Co. v. Carmichael, 526 U.S. 137, 154 (1999).

[125] Roby & McAllister, *Forensic Investigation Techniques for Inspecting Electrical Conductors Involved in Fire,* at 3.

[126] Buc et al., *Method to Characterize Damage to a Conductors from Fire Scenes,* at 655.

[127] *Daubert,* 509 U.S. at 579.

reasoning or methodology properly can be applied to the facts in issue."[128] Consequently, the first prong of *Daubert* centers on a determination of whether an expert's testimony is based on a reliable methodology. Factors that may be considered in determining the soundness of the scientific methodology include, but are not limited to:

> 1) Whether the theory or technique can be and has been tested;
> 2) Whether the theory or technique has been subjected to peer review and publication;
> 3) The known or potential rate of error and the existence and maintenance of standards; and
> 4) Whether the theory or technique used has been generally accepted.[129]

The question of whether the expert's technique or theory is scientifically reliable is a precise one. The issue is not whether the field over-all uses a reliable methodology, but the reliability of the expert's methodology in the case at hand, i.e. *whether it is valid for the purposes for which it is being offered*, or what the Court has described as an inquiry of "fit."[130]

It must be emphasized that "the trial court's role as gatekeeper is not intended to serve as a replacement for the adversary system."[131] "Vigorous cross-examination, presentation of contrary evidence, and careful instruction on the burden of proof are the traditional and appropriate means of attacking shaky but admissible evidence."[132] After all, a forensic expert's "junk science" left unchallenged is afforded

---

[128] *Id.* at 593.

[129] *Id.*

[130] *Id.* at 591 *(emphasis added).*

[131] Primrose Operating Co. v. Nat'l Am. Ins. Co., 382 F.3d 546, 562 (5th Cir. 2004).

[132] *Daubert*, 509 U.S. at 593.

great credibility in the eyes of juries, epitomizing an unreliable adversarial process.[133]

A. TESTING

Commentators have provided candid explanations about inadequate experimental verification of arc mapping as a measurement technique to evaluate the area of fire origin. The experiments conducted to date are not statistically based, involve dissimilar facts, and are subjective. In addition to the inherent methodological limitations of arc mapping, a range of other factors can affect practitioner accuracy and have not been tested and accounted for. These experimental limitations reveal significant limitations inherent to arc mapping accuracy and undermine its use as an admissible fire origin-related scientific technique.

B. PEER REVIEW & PUBLICATION

Daubert states that "publication in a peer-reviewed journal [is] a relevant, though not dispositive, consideration in assessing the validity of a particular technique or methodology on which an opinion is premised."[134] Nevertheless, publication and peer review "serve[s] as independent indicia of the reliability of the . . . technique" and "demonstrate[s] a measure of acceptance of the methodology within the scientific community."[135]

Regarding the use of arc mapping for area and point-of-origin determinations, the fire investigation scientific community is not a monolithic entity that has spoken in a single authoritative voice. A non-exhaustive growing body of quality scientific literature points to a scarcity of experiments and associated analyses to bolster the conclusion that there has been insufficient empirical validation in the fire investigative arena.

---

[133] *See* Melendez-Diaz v. Massachusetts, 557 U.S. 305, 319 (2009).

[134] *Daubert*, 509 U.S. at 594.

[135] Ruiz-Troche v. Pepsi Cola of Puerto Rico Bottling Co., 161 F.3d 77, 84 (1st Cir. 1998); *see also Daubert*, 509 U.S. at 593 ("[S]ubmission to the scrutiny of the scientific community is a component of 'good science.'").

Statistical insignificance in combination with quality issues surrounding the sparse research calls methodological trustworthiness into question. In fact, "[w]hile NFPA 921 does name 'arc mapping' as a potential tool in determining a fire's origin, it never identifies it as necessary."[136]

D. RATE OF ERROR

In *Trimboli v. State*, the court stated that:

> [t]he trial court has the right to assess the strength of the foundation for admissibility. That includes the right to know the accuracy and reliability of the technique on which the evidence is based. When the error rate is unknown, undisclosed, or unreasonably high, the trial court is justified in excluding the evidence. Lack of consensus in the scientific community concerning this factor may lead the trial or appellate court to conclude that the probative value of the evidence is substantially outweighed by the danger of unfair prejudice because of the uncertainty concerning the evidence's trustworthiness. In appropriate cases the court may well consider the lack of consensus in the scientific community as a factor that bears heavily on the admissibility decision.[137]

In *United States v. Bonds*, the court noted that:

---

[136] Occidental Fire & Cas. of North Carolina v. Intermatic Inc., 2013 WL 4458769, 2 (D. Nev. Aug. 15, 2013); *see also* Argonaut Ins. Co. v. Samsung Heavy Industries Co. Ltd., 929 F. Supp. 2d 159, 166 (N.D.N.Y. 2013) (The fact that expert did not conduct arc mapping did not render his opinion any less reliable nor did it automatically subject his opinion to preclusion.).

[137] Trimboli v. State, 817 S.W.2d 785, 790 (Tex. App. 1991).

> [t]he deficiencies in calculating the rate of error * * * [is] troubling," and the lack of evidence of a "rate of error is a negative factor in the analysis of whether the . . . procedures are scientifically valid." However, these concerns [go] to the weight of the evidence, not its admissibility.[138]

A mathematical error rate regarding arc mapping scientific methodology/practitioner error, when used in fire origin inquiries, has not been calculated. Limitations of accuracy and precision associated with measurement and testing techniques, when combined with incalculable differences in practitioner skill and/or experience, make it impossible to even approximate an error rate. Proponents of fire-origin related arc mapping are therefore relegated to drawing arbitrary lines without an evidentiary rate-of-error record to support this scientifically erratic procedure.

E. GENERAL ACCEPTANCE

"[G]eneral acceptance in the scientific field is highly probative of the reliability of a scientific procedure."[139] "'General acceptance' . . . means consensus drawn from a typical cross-section of the relevant, qualified scientific community."[140] "[T]rial courts, in determining the general acceptance issue, must consider the quality, as well as quantity, of the evidence supporting or opposing a new scientific technique. Mere numerical majority support or opposition by persons minimally qualified to state an authoritative opinion is of little value."[141]

Numerous reliable authorities have repudiated the theory that arc mapping methodology is scientifically reliable when used exclusively to determine fire origin. The existence of this significant controversy alone precludes a finding of general

---

[138] United States v. Bonds, 12 F.3d 540, 560 (6th Cir. 1993).

[139] State v. Montalbo, 73 Haw. 130, 138 (1992).

[140] 31 Cal. Jur. 3d Evidence § 441 (2020).

[141] People v. Leahy, 8 Cal. 4th 587, 612 (1994) (*emphasis added*).

acceptance. Moreover, the failure of arc mapping fire origin determination to satisfy the first three *Daubert* factors weighs against persuasive reliance on the general acceptance factor. The imprecise and speculative application of arc mapping to this area of fire investigation does not meet a level of certainty that inspires confidence in its trustworthiness.

XIII. ARC MAPPING: A LEGAL ANALYSIS

In *Glassman v. Home Depot USA, Inc.*, an experienced electrical engineering expert performed an arc mapping survey and thereafter confirmed the fire origin expert's conclusion that the area of origin was "on the top of a workbench in the garage."[142] The arc mapping expert then surveyed the designated area of fire origin for ignition sources and formed an "initial hypothesis was that a [defendant] Ryobi charger or battery sitting in the charger [on the workbench] was the cause of the fire."[143] After a laboratory CT scan of the benchtop battery revealed that it was not manufactured by defendant Ryobi and was not the hypothesized ignition source, the expert's ignition scenario and area of origin morphed into a "Ryobi batter[y] that investigators recovered *from the floor of the garage*."[144] (*emphasis added*). The court subsequently stated: "[t]o say this raises an eyebrow is an understatement," but irrespective of the arc mapping expert's "serendipitous changes of heart," ultimately ruled that his "opinions were shaky but admissible."[145]

In *Powell v. State Farm Fire & Cas. Co.*, after a basement fire occurred the fire investigator initially determined that "[a]n electrical issue caused the fire. It started above the circuit breaker panel involving the service conductor where it comes into the house."[146] The defendant insurance company thereafter

---

[142] Glassman v. Home Depot USA, Inc., No. 2:16-CV-07475-ODW-E, 2018 WL 3569344, at *2 (C.D. Cal. July 20, 2018).

[143] *Id.*

[144] *Id.*

[145] *Id.* at 5.

[146] Powell v. State Farm Fire & Cas. Co., 2:15-cv-13342-DML-MKM (E.D. Mich. May 13, 2016). *Plaintiffs' Motion To Exclude The Testimony*

transferred the fire claim to its large loss team and retained an electrical engineer to perform an arc mapping analysis to "rule out electrical."[147] The arc mapping expert performed a singular visual on-scene examination and determined that "the branch circuit conductors and associated electrical components located in the area of interest were not causal elements of the fire."[148] Armed with these newly minted forensic conclusions, the fire investigator's area of origin mutated into "the ceiling space, ["on top of a suspended ceiling tile in the basement bathroom"] approximately 21" east of the west wall and east of the circuit breaker panel."[149] The fire expert's rehabilitated fire classification opinion metamorphosed into *incendiary* due to "the introduction of a combustible material on top of a lay-in-ceiling and ignited with an open flame."[150]

The fluctuating hypotheses in the above cases were "built upon the shifting sands of 'junk' science or a 'junk' scientist."[151] More than the misapplication of validated methods or deficiencies in qualitative analysis, these cases epitomize outlandish and unsupported pronouncements based in part upon a speculative methodology that is prone to manipulation. In *Gen. Elec. Co. v. Joiner*, the Court noted that:

> conclusions and methodology are not entirely distinct from one another. Trained experts commonly extrapolate from existing data. But nothing in either *Daubert* or the Federal Rules of Evidence requires a district court to admit opinion evidence that is connected to existing data only by the *ipse dixit* of the expert. A court may conclude that there is simply too great an analytical

---

Of Defendant's Fire Origin And Cause Expert, David Stayer (Oral Argument Requested) at 9.

147 *See id.* at 18 (31).

148 *See id.* at 8 (15).

149 *See id.* at 10 (19).

150 *See id.* at 11 (20).

151 *Ex parte* Robbins, 478 S.W.3d 678, 706 (Tex. Crim. App. 2014).

> gap between the data and the opinion proffered.[152]

The above cases exemplify an analytical *chasm* between the available data and the opinions reached-- an abyss too great for even neophytes to conclude that fire-investigative arc mapping methodology was reliably applied to the presented facts to establish fire origin.

XIV. CONCLUSION

Arc mapping as a forensic tool to determine area/point of fire origin has glaring limitations. Limited experimental verification and subjective evaluative methodologies render this imprecise procedure inconsistent, unreliable, and therefore untrustworthy as a matter of law.

The substandard arc mapping practices that are presently permeating the fire investigation landscape amount to an analytical leap from subjective qualitative considerations to self-styled quantitative conclusions. Metallurgic characteristics and microstructural modifications have been relegated to the back burner while pure speculation and guesswork has been elevated to competent proof. An in-depth metallurgical analysis and resulting laboratory confirmation utilizing microscopic magnification constitutes best practices to discriminate between arc marks and unrelated conductor anomalies meaningfully to ensure reliability and to maximize the likelihood of admissibility.

---

[152] Gen. Elec. Co. v. Joiner, 522 U.S. 136, 146 (1997).